



IT CORPORATION

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Final Report

Site Study - Phase I

Baltimore Chrome Works
Baltimore, Maryland

*Allied Chemical Company
Baltimore, Maryland*

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Final Report

Site Study - Phase I

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EXECUTIVE SUMMARY

IT Corporation (IT) was retained by Allied Chemical Company (Allied) to complete a site assessment of the Baltimore Chrome Works, located on the Inner Harbor in Baltimore, Maryland. The objectives of the assessment are as follows:

- Develop a comprehensive understanding of current site geologic and hydrogeologic conditions
- Determine the impact of current and past waste disposal and chemical production operations on the local environment
- Characterize the amount, location, condition, and nature of process wastes in the site subsurface and identify active contaminant sources
- Identify and evaluate pathways of contaminant migration that may impact human health or environmental quality, with particular attention given to bulkhead integrity and the underground storm sewers.

Chromium ore processing has taken place at this location since the mid-1840s. Throughout the history of the site, periodic redevelopment and upgrading of facilities and process methodologies have taken place. The primary production facility, the bichromate plant, was relocated and modernized in the early 1950s. The bichromate plant was formerly located in the area now occupied by the plant's parking lot. The list of chromium compounds manufactured at the site has grown over the years, primarily due to the addition of a special products unit constructed in the 1950s. This unit has been used primarily for the manufacture of chromic acid and chromium sulfate products. The chromite processing and manufacture of chromium products is a water-intensive process, with large quantities of water required for housekeeping procedures. Many of the chromium products react corrosively with the floors of the production facilities.

At the start of site investigations, known or suspected sources of chromium migration included buried process ore residue beneath the site which is in contact with ground water and floor leakage from the bichromate plant leaching area and the special products production area.

Methods of Investigation

IT researched the plant files and contacted numerous agencies and institutions to gain information on site history and regional environmental quality. Existing site data were used throughout the study to confirm findings and to direct changes in the field program. IT worked in cooperation with the diver hired by Allied to evaluate the bulkhead integrity. With IT's instruction, the diver also inspected storm sewer outfalls at the harbor and collected sediment samples at selected locations along the plant's bulkhead. Eleven ground water monitoring wells and five soil borings were installed on site; resultant soil and ground water samples, along with water and sediment samples from the harbor, were returned to IT's laboratory for analysis. Hydraulic conductivity tests were conducted in the wells, ground water level and corresponding harbor water level measurements were made, and observations made concerning the surficial condition of the storm sewers.

Selected soil samples were analyzed for iron, barium, and total and hexavalent chromium and for EP toxicity leachate test metals and hexavalent chromium. Water samples were analyzed for several general chemistry and metallic parameters.

Major Findings

The site is underlain by four stratigraphic layers. A layer of miscellaneous fill materials is found at the ground surface over all of the site except the area south of the main office building. The fill materials were generally less than 10 feet in thickness, although some areas contained fill in thicknesses greater than 20 feet. Visible chromium contamination was frequently observed in these materials. Fill mate-

rials contained up to 34,000 parts per million (ppm) total chromium and 2,900 ppm hexavalent chromium.

A very soft clayey silt layer was encountered beneath the fill layer along the perimeter of the site, but was not found in the central portions of the site. Chromium concentrations in this layer were as high as 26,000 ppm total chromium and 4,900 hexavalent chromium. Highest amounts were found in the area of the old bichromate plant, near the refuse storage bin, and north of the special products unit. This layer has a low permeability value, but the fact that it is absent from the central portion of the site indicates it has little impact on ground water flow at the site.

A dense fine to medium sand layer, ranging from approximately 5 to more than 20 feet in thickness, was found underlying the entire site beneath the soft silt layer. Despite its high density, the sand layer is quite permeable and in several locations yielded soil or water samples containing visible chromium contamination. This layer is at or near ground surface in the central portions of the site where the fill and soft silt layers are largely absent. Total chromium concentrations of the sand layer were normally less than 100 ppm, but were as high as 1,700 ppm in the vicinity of the old bichromate plant and the special products unit. Most chromium found in samples from these areas was in the hexavalent form.

A very hard silt and clay layer was encountered beneath the sand at depths of 35 to 50 feet. It is likely this layer represents the maximum depth of vertical migration of chromium beneath the site. This was indicated by the very high blow counts required for sampling of this layer and the fact that the drilling equipment utilized was unable to penetrate this layer to any significant depth. Chromium values of soil samples taken from this layer were generally less than those from overlying strata. Regional data suggest this layer may be as thick as 150 feet.

Site Chromium Distribution

Chromium is present throughout the site soils and ground water, with the highest concentrations usually found at those locations nearest the present production facilities (the bichromate plant and the special products unit) and in the vicinity of the former bichromate plant. Higher concentrations of chromium were found in ground water than in the soils at most sampling locations, and nearly all of the chromium was found in the hexavalent form. Total chromium in ground water was as high as 9,200 ppm, while hexavalent chromium was found in concentrations as high as 8,000 ppm. These findings, along with the high sodium concentrations found in ground water samples collected near the bichromate plant, indicate the production facilities may be a significant source of subsurface chromium contamination. Buried ore residues are another source of subsurface contamination, particularly in the south slip area where large quantities are known to have been buried. No chromium was found in the ground water sample obtained immediately east of the plant property.

Off-Site Chromium Migration

Ground water migrates beneath the site from the east and discharges to the north, west, and south, either directly into the harbor or beneath the harbor floor through the sand layer. Mass loading calculations indicate approximately 20 to 25 pounds of chromium per day discharge from the site via ground water flow; approximately 80 percent of this amount is in the hexavalent form.

The site's storm sewer network is largely sealed or plugged and acts only as a minor conduit for off-site chromium migration. The bulkhead surrounding three sides of the site is generally in good structural condition, with the exception of the section around the northwestern corner of the plant property which is in very poor condition. Several small liquid and fill material leaks in the bulkhead were noted by the diver, particularly in the Back Basin.

Harbor waters contained no hexavalent chromium except in the vicinity of the northwestern corner of the plant property, where 7.5 ppm hexavalent chromium was found. This same sample also contained 14 ppm total chromium. With the exception of the sample taken off the northwestern corner of the bulkhead, harbor sediment samples contained less than 3 ppm hexavalent chromium and around 200 ppm total chromium. The sediment sample from the northwestern corner of the bulkhead contained 130 ppm hexavalent chromium and 1,800 ppm total chromium. However, none of these sediment samples released any chromium when leached according to the Extraction Procedure (EP) Toxicity test. The harbor sediments are apparently providing an effective reducing environment for hexavalent chromium, as evidenced by Eh measurements of the sediments, and further provide ample exchange sites for immobilization of the trivalent form.

ALLIED CHEMICAL COMPANY
BALTIMORE CHROME WORKS
SITE STUDY - PHASE I

1.0 INTRODUCTION AND OBJECTIVES

Allied Chemical Company (Allied) has owned and operated a chrome chemicals manufacturing facility in Baltimore, Maryland since the early 1950s. The facility, which is located in downtown Baltimore on the Inner Harbor as shown in Figure 1, initially began chrome chemical production in the 1840s. Periodic redevelopment and upgrading of the site and chrome chemical production facilities have occurred throughout the history of the plant. The present site configuration is presented in Figure 2. The most recent expansion involved reclaiming land in the southwestern portion of the site in the 1960s to expand the ore roasting and leaching operation. The current plant site is bordered by the Inner Harbor on the north, west, and south and by Wills Street on the east. The site is essentially flat, with most of the property either paved or covered by buildings or other structures. The majority of surface runoff and roof drainage eventually reach the harbor. The ground surface elevation in the plant is about six to eight feet above the harbor mean low water level elevation of 94 feet, relative to plant datum.

The manufacturing process, which involves roasting and subsequent leaching of chrome ore, is waste intensive. Process residue containing up to 0.5 percent of soluble chrome (possibly more in older residue) has been historically deposited and used for fill material at the plant site, as well as at other locations in the Baltimore Harbor area, and has been assumed to be a potential source of ground water contamination at the site. Plant records indicate residue was deposited in the south slip area and a test patch area behind the main office building. Sodium sulfate produced in the soda plant containing up to 0.5 percent sodium chromate may also be buried at various locations on the plant site.

Another primary potential source of contamination is floor leakage in the leach area, soda plant, and chromic acid or special products units. The production processes and housekeeping procedures are water intensive and the chemicals produced in the sodium bichromate and chromic acid plants are corrosive to the concrete and brick floors of the building.

Two potential sources of off-site contaminant migration were suspected before the Phase I study began. These are the old storm sewer network beneath the site and permeable areas of the bulkhead surrounding the site. Allied has historically noted some discoloration in portions of the ice which forms in winter off the bulkhead, suggesting some contaminant migration from the site. The storm sewers are primarily public works remnants which were installed when the streets were the property of the City of Baltimore. The bulkhead has apparently been in existence in one form or another since the earliest days of the plant's history. Several additions, repairs, and reconstructions of portions of the bulkhead have occurred over the years.

The Phase I study was undertaken by IT Corporation (IT) to address the following objectives:

- Develop a more comprehensive understanding of current site geologic and hydrogeologic conditions
- Determine the impact of current and past waste disposal and chemical production operations on the local environment
- Characterize the amount, location, condition, and nature of process wastes in the site subsurface and identify active contaminant sources
- Identify and evaluate pathways of contaminant migration that may impact human health or environmental quality, with particular attention given to bulkhead integrity and the underground storm sewers.

2.0 SITE HISTORY

Chromium ore (chromite) has been processed at the site since 1845 when Isaac Tyson started the first plant of its kind in the United States. Some years earlier, Tyson had discovered extensive chromite deposits in the vicinity of Jarrettsville, Maryland, about 25 miles north of Baltimore. Immediately acquiring rights to the property, Tyson began mining the ore for shipment to England. Later, he succeeded in establishing a potassium bichromate plant, choosing the Baltimore site probably because of its waterfront, available labor supply in the city, and proximity to the ore deposits. Tyson's operations were confined primarily to a seven-bay building located in the 1300 block (north side) of Block Street. The two westernmost bays of the building remain today and are still utilized. A few support facilities, such as a carpenter shop and stables for horses used in the plant, were located along the south side of Block Street from the middle of the 1300 block continuing west to Point Street and south to Philpot Street. Block Street at the time was apparently a major thoroughfare into the city, as it connected just west of the plant with a drawbridge which extended westward to an extension of West Falls Avenue, which ran along the west side of Jones' Falls and intersected Pratt Street. The drawbridge was dismantled in 1906.

In 1908, Tyson's plant became the property of Mutual Chemical Company (Mutual) which had additional chromium operations in Jersey City, New Jersey. While the basic function of the plant has historically been the processing of chromite ore, some of the process methodologies have changed over the years. Plant records show that ground oyster shells were used in place of lime in the roasting process up through at least the late 1920s. Many oyster shell fragments were encountered by several of the borings installed by IT during this study. According to historical accounts, the shells were piled in a yard near the old plant, transported by cart into the plant, ground in mills, then mixed with coal and sulfate prior to roasting and leaching. The liquor obtained from the

leaching was mixed with pulverized ore and lime (presumably also ground oyster shells) and perhaps some soda ash to obtain a "wet mix." This mix was then roasted in the 20 coal-fired reverberatory furnaces in the plant. Each furnace held five roasting beds. The bed nearest the firebox would be removed upon completion of roasting. The remaining beds were moved sequentially toward the firebox and a newly recharged bed was added to the furnace. The completely roasted matrix from the removed bed was dumped beside four square filter tanks which were set halfway below the plant floor. The roasted matrix was then shoveled into the filter tanks, leached, and the resulting liquor was pumped off. After leaching, residue was shoveled from the filter tanks into a horse-drawn cart, hauled across Dock Street, and shoveled into a scow docked in the Back Basin which was routinely hauled away for refuse disposal. Prior to 1916, the majority of the plant's refuse was hauled away for disposal on the Curtis Bay side of the Patapsco River, although the exact location is not identified in plant historical records. In 1916, a monorail crane runway was installed to transport refuse from the filters to the scows. Also at this time, certain properties in Dundalk were purchased and developed for Mutual's refuse disposal. Refuse dryers and mills were also installed at the plant in 1916.

One former Allied employee who worked at the site during the time refuse scows were utilized stated that it was frequently necessary to dredge accumulations of refuse from the Back Basin along the bulkhead. Refuse was handled in the same general fashion with periodic refinements until approximately 1946, when Mutual began hauling refuse to Dundalk by truck.

A special products unit was erected at the site in 1920, on the northern side of the 1200 block of Block Street. Prior to this time, this property was occupied by a company which cut granite blocks for use as paving stones and is credited with supplying most of the block used in Baltimore's turn-of-the-century streets. Bichromate of soda was one of

the primary products manufactured here, and its production resulted in substantial quantities of sodium sulfate being generated as a by-product. Sodium sulfate was apparently disposed with the ore refuse (plant historical records do not definitively describe final disposition) as there was little or no market for this material at that time. The bulk of the bichromate production at that time was in large crystals, with lesser amounts produced in granular form. The chromate liquor was placed in boiling pans for "finishing," then run off into vats for cooling and crystallization, a process which took 12 to 15 days. The crystals were removed from the vats with picks and shovels, then washed, dried, and packed.

In 1926, Mutual began phasing out the coal-fired furnaces when it installed a pilot plant oil-fired rotary kiln in the bichromate plant. Rotary kilns are utilized exclusively in the plant today. Some coal apparently remained in use at the site until at least the mid-1960s, as suggested by site historical information. In the early 1930s, Mutual transferred its KoreonTM and potash bichromate plants from its Jersey City facility to Baltimore. In 1936, potassium chromate was added to the list of chromium products manufactured at the site. It is approximately at this point in the plant's history where photographic evidence of site facilities becomes available.

Figures A-1 through A-6 in Appendix A present aerial photographs of the site with the main facilities highlighted. Figure A-1, which depicts the site in 1938, is an enlargement of a section from the area's oldest known aerial photograph held by the National Archives. The plant at this time was still owned and operated by Mutual. According to historical accounts, the primary change in plant configuration between the turn of the century and that shown in Figure A-1 is the addition of the KoreonTM and other "special products" facilities (shown as 10 through 18 in Figure A-1) to the west of the bichromate plant. As discussed previously, these facilities were constructed in the early 1930s. The 1938

site representation shows what appears to be a refuse scow moored in the Back Basin along the plant's northern bulkhead. It is possible this is a coal barge, as the coal hopper and refuse loading system were located near each other around this time; it is uncertain exactly when the coal hopper was abandoned at the old plant. Figure A-1 also depicts a very irregular shoreline and land surface along the northwestern corner of the plant property. It appears that a substantial volume of rubble or fill materials occupies this area and extends several feet out into the harbor west and north of the plant. This same figure depicts the yard south of the main office building as being the plant's ore storage area. This area was apparently unpaved until the mid-1930s, when sections of it were paved.

Plant historical records indicate that at one time a deep well existed inside the old bichromate plant which was utilized for withdrawal of cooling water. The depth of this well was reportedly 1,000 feet, which seems unlikely, as this would be well into crystalline rock which usually is unfractured and contains little or no ground water. However, plant records indicate the well was located near the center of the area presently occupied by the employee's parking lot. The only well construction records found were brief, indicating the well was 10 inches in diameter and cased to 30 feet. Other records were found indicating a well pump was installed in 1937 in the old plant's "deep artesian well," then removed in 1945, presumably when the use of municipal water was initiated in the plant. Additional records noted that in 1938, ten borings were drilled at the site in an attempt to locate an artesian water source for the plant. Boring locations and logs were not found, but it was learned that no suitable water source was found and that bedrock was encountered approximately 250 feet below ground surface.

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In the late 1940s, the old facilities for Koreon™ and potassium bichromate manufacturing were completely replaced. In 1948, construction of a new bichromate plant was begun on the southwest corner of the property

on the former site of the Hammond Ice Company's Block Street Wharf and Warehouse. Mutual had obtained this property in 1940. A lumber company occupied this area prior to the ice company, and a harbor slip which they utilized was covered prior to construction of the ice company warehouse. No records were found which indicated the nature of the cover or what improvements, if any, Mutual made to the cover prior to construction of the new bichromate plant. Borings placed in this area prior to construction of the new plant encountered up to 23 feet of material described as "miscellaneous fill," and one former employee who worked at the site during this time indicated these materials may consist of ore refuse.

The new bichromate plant went on line in October 1950, having been built at a cost of \$13.2 million. The old plant on the northern side of Block Street was phased out and eventually was shut down in 1951, then dismantled in 1953. Figure A-2 is an aerial photograph depicting the site in 1952. Both the old and new bichromate plants are visible in the photograph. The new potash, Koreon™, and chromic acid plants are depicted here, as are new acid, fuel oil, and liquor storage tanks. This figure also shows approximate boundaries of several other adjacent or nearby properties which Mutual obtained in the late 1940s and early 1950s. The original aerial photograph for 1952 shows small plumes of darkened water which appear to be emanating from the property's northwestern corner at approximately the same location as two storm sewer outlets and also from the outlet west of the bichromate plant. While not readily visible on the reproduced version of Figure A-2 contained in the report, these plumes can be seen on the original photographs which were submitted to Allied under separate cover.

In 1954, Mutual was acquired by Allied. Allied continued with the plant modernization program and also acquired the remainder of the property on the peninsula during the mid-1950s. Figure A-3 depicts site facilities in 1957. The property boundary shown here is similar to that which

exists today. This photograph shows that the old bichromate plant has been demolished and that an ore stockpile occupies a portion of the old plant site. Additional ore storage areas appear on the former Bowie Smith property and east of the old Miller building in the southeastern corner of the plant property. A small coal stockpile is also visible on the old Bowie Smith pier on the plant's southern extreme. New shops and stores built by Allied are also seen in this photograph. The former Marine Railway harbor slip (known as the south slip) near the southwestern corner of the site appears to have been partially filled in, as compared to the 1952 photograph (Figure A-2). This photograph gives indications that backfilling of the south slip took place in two stages. While plant records indicate ore refuse was placed here in the latter backfill stage, it is uncertain what types of materials were placed here during the initial backfilling operation. An active discharge into the harbor can be seen off the western bulkhead near the center of the bichromate plant. It is in approximately the same location as the currently utilized No. 2 cooling water discharge. Since there is no discoloration noted in the 1957 photograph, it is assumed the discharge was comprised of cooling water at the time also.

The 1964 aerial photograph (Figure A-4) reveals the addition of the tank farm west of the special products facility and some reconfiguration of the chromic acid and sodium chromate plants. Further changes in the south slip appear to have occurred as compared to the 1957 configuration. The site of the old bichromate plant appears totally vacant. On the former Bowie Smith property, a new storage area for either coal, ore, or possibly refuse appears in the south-central portion of the property. This storage pile appears to be surrounded by a white circle of material of unknown composition.

The 1971 aerial photograph (Figure A-5) includes the western bulkhead extension which was added in the late 1960s. Off-site materials were brought in for filling behind this new bulkhead. The south slip has

been further reconfigured, while other pier extensions along the plant's southern shore have either been removed or have collapsed to some degree. More ore storage areas are visible in the southeastern portion of the plant property, and the coal stockpile is noticeably absent from the Bowie Smith pier. The former location of the old bichromate plant appears paved and has become the plant parking lot.

The most recent aerial photograph (1981 - Figure A-6) is very similar to the current site conditions. The only notable changes as compared with the 1971 site configuration are the further deterioration of piers along the south shore and the addition of a storage yard and helicopter pad on the Bowie Smith property.

3.0 STUDY METHODOLOGIES

3.1 EXISTING DATA SEARCH

IT contacted numerous governmental and private institutions to obtain existing data to characterize past site land use changes and regional environmental quality. The largest single source of this information proved to be plant records, drawings, and other files maintained by Allied at the site. These files provided information on storm sewer locations, plant facilities identification and details, bulkhead construction details, diver's historic bulkhead inspection reports, the location of known areas of fill on site, and historical site drawings and reports. Of particular interest and value were a series of reports completed over the past 40 years which presented details of pile driving efforts for foundations in advance of various site construction projects. These pile driving operations nearly always included a series of subsurface borings which were utilized to identify subsurface conditions at each location. Allied's plant files yielded approximately 117 boring logs which depict subsurface site conditions; IT used these logs to assist in selection of soil boring and monitoring well installation locations and to confirm our findings concerning site geology. IT also interviewed three long-time plant employees who provided insights to historic plant operations and confirmed the location of other potential contaminant sources.

Aerial photographs were obtained which depict the site at six different intervals between 1938 and 1981. The oldest photograph was obtained from the National Archives; the remainder were obtained from the U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service, Aerial Photography Field Office. These photographs are discussed in Chapter 2.0 and reproductions of the relevant portions of each are presented in Appendix A. The actual photographs have been submitted under separate cover to Allied.

Numerous agencies and institutions were contacted to obtain environmental quality information for the area surrounding the site, particularly data which presented chromium values for ground waters, surface waters, and harbor sediments immediately surrounding the site, or provided information on the history of the site. Allied plant records provided site-specific information as Allied has conducted analyses on soil, ground water, and harbor water samples collected at the plant on various occasions. U.S. Environmental Protection Agency (U.S. EPA) publications provided general information on the Chesapeake Bay system, although it was necessary to contact various organizations for more specific information on the Inner Harbor region. Following is a list of the organizations from which usable data were obtained:

- U.S. Army Corps of Engineers (U.S. COE),
Baltimore District
- Maryland Port Authority
- Baltimore Museum of Industry
- City of Baltimore, Public Works Department
- U.S. EPA, Chesapeake Bay Program
- Maryland Department of Natural Resources
- Maryland Geological Survey (MGS)
- U.S. Geologic Survey (USGS)
- University of Maryland Center for Environmental
and Estuarine Studies.

Allied's confidentiality was protected by IT when making these contacts. Some of the information gathered from the contacts is included in the site history discussion presented in Chapter 2.0; the remainder is included in Section 5.2 of this report.

3.2 FIELD PROGRAM

IT designed and implemented a field program to characterize site subsurface conditions and determine the chromium content of ground water and geologic strata beneath the site. During late 1984 and early 1985, IT installed 11 ground water monitoring wells and five exploratory borings at the site at the locations shown in Figure 2. In all borings, soil samples were collected at 2.5-foot depth intervals in accordance with the American Society for Testing and Materials (ASTM) Procedure D 1586. Soil borings drilled for subsequent monitoring well installation were advanced using a truck-mounted rotary drill rig and ten-inch outside-diameter (O.D.) hollow-stem augers; exploratory soil borings were advanced using six-inch hollow-stem augers. Boring logs are presented in Appendix A. Monitoring wells were constructed with four-inch inside-diameter (I.D.) Schedule 40 polyvinyl chloride (PVC) pipe (threaded, flush joints), typically with either a five- or ten-foot (nominal) length of slotted well screen with a 0.010-inch slot size. Gravel pack filter materials were placed in the annulus from the bottom of the boring to several feet above the top of the screened interval. Bentonite pellets were placed on top of the gravel pack in most monitoring wells to provide a seal against downward migration of surface water. In two wells, bentonite pellets could not be placed through the augers. In these cases, a thick bentonite slurry was tremied into place. The remainder of each boring annulus was grouted to the surface with a cement-bentonite slurry. Wells were constructed flush with ground surface and encased in a standard metal gate box. Well installation details for each monitoring well are included in Appendix B. Borings in which no well was installed were grouted to ground surface upon completion.

All monitoring wells were developed utilizing a submersible pump rated at ten gallons per minute. Wells were pumped until either the visible silt content of the water was insignificant or until the well pumped dry. Wells which pumped dry were allowed to recover, then pumped until dry again, a procedure which was usually repeated three times. All

monitoring wells were purged again of at least three well volumes of water immediately prior to sampling. In all wells except W-10, the rate of water level recovery was measured in the wells following pumping. These rising head test data were used to calculate permeability values at each location. The rising head test methodology was selected due to its ease of operation, its applicability to site geologic conditions encountered, and site constraints regarding pumping contaminated ground water onto the site surface. Rising head test data are normally comparable to results obtained by either falling head or constant head methodologies. Packer tests were not suited to site geology. Pump tests may have provided more accurate data, but were not conducted due to their time and cost requirements, as well as the problem presented by disposal of the contaminated ground water which would be pumped from each well.

Ground water samples were obtained from the monitoring wells using a Kemmerer-type well sampler. Samples for metals analysis were filtered in the field prior to preservation and packing for transport to IT's laboratory. Three water samples were obtained from locations in the harbor surrounding the site as shown in Figure 2. Both filtered and unfiltered samples were obtained from the harbor in order that analyses could be conducted for both dissolved and total metals. Ground water samples were also obtained from three of the five exploratory borings (B-2, B-3, and B-5) through the augers prior to withdrawal from the boring. Field pH, Eh, temperature, and specific conductivity measurements were made for each water sample.

Sediment samples from the harbor floor were also obtained at the three harbor sampling locations shown in Figure 2. Samples were sealed in amber jars while under water and were obtained by the diver conducting the bulkhead inspection for Allied concurrent with IT's site studies. Additionally, the diver later obtained a fourth sediment sample which contained a quantity of crystalline residue found along the bulkhead which was also submitted for analysis.

3.3 LABORATORY PROGRAM

3.3.1 Soil Samples

A total of 49 soil samples and four harbor sediment samples were returned to IT's laboratories and submitted for analysis. A portion of each sample was digested in perchloric acid and the digest analyzed for the following metals by atomic absorption spectrophotometry:

- Total chromium
- Hexavalent chromium
- Barium
- Iron.

A separate portion of each sample was leached according to the Extraction Procedure (EP) Toxicity test procedure (1980) and the leachate analyzed for the following metals:

- Arsenic
- Barium
- Cadmium
- Total chromium
- Hexavalent chromium
- Lead
- Mercury
- Selenium
- Silver.

With the exception of the four harbor sediment samples, all soil samples were eventually forwarded to Gascoyne Laboratories of Baltimore (Gascoyne) for hexavalent chromium analysis. Gascoyne utilized a colorimetric procedure in which a small volume of soil extract is prepared using potassium dihydrogen phosphate which is then reacted with diphenyl carbazide prior to determining transmittance with a colorimeter (Reisenauer, 1982). IT encountered difficulties in analysis of several of the total soil acid digests for hexavalent chromium. Most of the digests gelled when complexed with methyl isobutyl ketone (MIBK) prior to aspiration into the atomic absorption spectrophotometer. This reaction is normally associated with excessively high amounts of iron, a

condition found to exist in many of the Allied samples. This problem may have been complicated by the high concentrations of total chromium found in many soil samples. Additionally, it is likely that the soil digestion in perchloric acid, a strong oxidant, was converting large amounts of trivalent chromium into hexavalent chromium. In the interest of time, Allied elected to have the samples analyzed by the colorimetric method rather than continue with the excessive dilution factors necessary to obtain results from the originally selected methodology.

A "mothball-like" odor was detected in the field in one soil sample obtained from Boring W-4 at a depth of 21 feet. This sample was subjected to analysis by gas chromatography and mass spectrophotometry (GC/MS) in an attempt to identify the odor-causing compound(s) present. *what was it*

3.3.2 Water Samples

A total of three harbor water samples and 14 ground water samples were collected by IT and submitted to IT's laboratory for analysis. Additionally, at the beginning of the field program, Allied submitted three additional water samples to IT for analysis. These had been collected in the harbor by the diver. The small volumes of these samples prevented analysis for some of the requested parameters.

Samples were analyzed in the field for pH, Eh, temperature, and specific conductance. Samples were then returned to the laboratory for the following analyses:

- | | |
|-------------------------|-----------------------|
| ● Acidity/alkalinity | ● Calcium |
| ● Filterable residue | ● Iron |
| ● Nonfilterable residue | ● Magnesium |
| ● Total organic carbon | ● Manganese |
| ● Chloride | ● Potassium |
| ● Silica | ● Cadmium |
| ● Sodium | ● Total chromium |
| ● Arsenic | ● Hexavalent chromium |
| ● Barium | ● Lead |
| ● Nitrate | ● Mercury |
| ● Sulfate | ● Selenium |
| ● Aluminum | ● Silver |

The three harbor water samples collected by IT (S-1, S-2, and S-3) were analyzed for both total and dissolved metals. Ground water samples were analyzed for dissolved metals (filtered samples).

3.3.3 Crystalline Samples

One harbor water sample and one sediment sample collected for Allied by the diver contained some white crystalline materials which the diver had observed on the bulkhead in two locations. These crystals were subjected to X-ray diffraction and energy dispersive analysis by IT in order to determine their mineral and elemental constituents.

Results of soil, water, and crystalline analyses are included in the discussion in Section 5.3 of this report.

4.0 REGIONAL AND SITE SETTING

4.1 REGIONAL SETTING

The site is located on the Patapsco River within the City of Baltimore, on the eastern side of the Inner Harbor (Figure 1). Baltimore covers approximately 80 square miles with a population density of 9,793 persons per square mile (U.S. Department of Commerce, 1982). The areas near the Baltimore Chrome Works are largely occupied by commercial and light industrial facilities, although some residential areas can be found within a mile north and east of the site.

The City of Baltimore lies in a region midway between the rigorous climates of the north and the milder climates of the south, and adjacent to the modifying influences of the Chesapeake Bay and the Atlantic Ocean to the east, and the Appalachian Mountains to the west. Since the city is near the normal path of low pressure systems which move across the country, changes in the weather and wind direction are frequent. The annual prevailing wind in Baltimore is from the west. Destructive wind velocities are rare and occur mostly during summer thunderstorms. Only rarely have hurricanes in this area caused widespread damage, then primarily by flooding.

Rainfall distribution throughout the year is uniform, with the greatest intensities in the summer and early fall months. Annual precipitation for 1983 in the City of Baltimore was 51.03 inches. During the summer months, the area climate is influenced by a large semipermanent high pressure system commonly known as the Bermuda High which centers over the Atlantic Ocean near the 30 degree North latitude. This high pressure system brings a circulation of warm, humid air masses over the area from the deep south. The inflow of these southerly winds combined with the proximity of large bodies of water give the area high relative humidities during this time of the year.

Annual average temperature in the City of Baltimore for 1983 was 55.3 degrees Fahrenheit, with January being the coldest month and July being the warmest. Although varying greatly, average annual snowfall is 21.5 inches. Snow is frequently mixed with rain and sleet and seldom remains on the ground for longer than a few days. The freeze-free period is approximately 194 days, with spring arriving in mid-April and fall in late October.

The City of Baltimore is located on a fall line which separates two major physiographic provinces: the Piedmont Province to the northwest and the Coastal Plain to the southeast. Surficial drainage in the site vicinity generally flows to the southeast in the direction of the dip of the unconsolidated deposits of the Coastal Plain sediments, into the estuaries of the Patapsco River, eventually reaching the Chesapeake Bay and the Atlantic Ocean.

The Northwest Branch of the Baltimore Harbor (known as the Inner Harbor) on which the site is located is an estuary of the Patapsco River. The Patapsco flows along the western edge of the Chesapeake Bay for approximately 14 miles and drains an area of approximately 611 square miles.

Historical uses of the Patapsco River, such as fishing, crabbing, and swimming, have substantially declined or have been abandoned as a result of harbor transport activities and the degraded quality of its water and sediment. Currently, the major uses of the river consist of commercial freight transport, waste assimilation, industrial water supply, and recreational boating. The Inner Harbor area also utilizes the aesthetic value of the river as the centerpiece for recreational and commercial activities for the City of Baltimore.

The lower Patapsco River is characterized by weak estuarine circulation, with on the order of 95 to 100 percent sediment trapping efficiency, which results in limited flow and flushing of the estuary. This causes

most effluents or sediment-laden runoff entering the estuary to remain in the upper estuary. Since the sediment and municipal/industrial effluent load is not readily dispersed by the system, stresses rapidly increase on the local ecosystem.

Dredging operations have not been undertaken in the Inner Harbor for several decades. The U.S. COE has never dredged the Inner Harbor beyond the turning basin located at the Domino Sugar Company facilities, located south-southeast of the Allied plant. This basin was last dredged in 1957. The U.S. COE stated that Bethlehem Steel Corporation used to conduct some limited dredging along the western side of the Inner Harbor for channel maintenance around their now-abandoned shipyards.

4.2 REGIONAL GEOLOGY AND HYDROGEOLOGY

Baltimore lies on the boundary between two physiographic provinces: the Piedmont Plateau to the west and north and the Coastal Plain to the south and east. The Piedmont Plateau is comprised geologically of Precambrian crystalline rocks such as gabbro, granite, gneiss, and schist, with small amounts of quartzite, marble, and granite pegmatite. Any storage or transmission of ground water in these rocks is a function of secondary fracturing of the formation caused by such activities as earth movement and weathering. These porous, permeable zones are not uniform and gradually disappear with depth.

In contrast, the Coastal Plain deposits, on which the Baltimore Chrome Works stands, consist of arkosic sands and gravels of Cretaceous and Pleistocene ages. These materials are generally quite permeable. Although irregularly bedded and lenticular, the various sand and gravel layers are sufficiently interconnected to form several relatively uniform and widespread ground water reservoirs. These reservoirs are recharged primarily by precipitation on the exposed edges or outcrops of the water-bearing formations. Except in these areas of outcrop, the

water in these Coastal Plain reservoirs occurs under artesian conditions. Figure 3 presents a generalized stratigraphic column for the geology of the Baltimore area, and identifies those formations which were encountered by IT during installation of the site ground water monitoring wells and borings.

4.3 SITE GEOLOGY AND HYDROGEOLOGY

The Allied site lies on lowland deposits of Quaternary age, near outcrops of related formations of the Potomac Group (Maryland Geological Survey, 1968). The Quaternary deposits consist of medium- to coarse-grained sand and gravel, varicolored silts and clays, and brown to dark gray lignitic silty clay. Their thickness in eastern Maryland ranges from 0 to 150 feet.

is this isolated

The nearby outcrops of the Potomac Group are comprised of interbedded quartzose gravels, argillaceous sands, and white to dark gray to multi-colored silts and clay. Regional thickness ranges from 0 to 800 feet. Several of the deeper borings installed on site by IT encountered some materials which appear to be constituents of the Patuxent Formation, a member of the Potomac Group. Most notable among these materials was a white or pale gray hard silt or clay encountered normally about 50 feet below the site which is described as a common constituent of the Patuxent Formation. This layer probably consists of kaolin clays, derived from the decomposition of feldspar. From this data, it appears that the site is underlain by a relatively thin veneer of Quaternary deposits which are in turn underlain by the Patuxent Formation.

In addition to the wells and borings installed by IT, Allied's files yielded boring logs for approximately 117 additional borings which were drilled on site at various times in the plant's history, usually in advance of various pile driving activities. The locations of these borings are shown in Figure 4. These borings were logged by the Raymond Corporation between 1941 and 1972. The logs were used to help select

well installation locations and confirm IT's subsurface findings. The reliability of the existing boring logs is good, as IT's drilling activities normally encountered materials similar to those indicated on logs for nearby historic borings.

The existing boring logs were also utilized to supplement IT's data in the preparation of site geologic cross sections. The cross section locations are shown in Figure 4 and the cross sections presented in Figure 5. Boring logs for borings completed by IT are included in Appendix B. In general, the cross sections reveal that site stratigraphy in the upper 50 feet consists of four major stratigraphic units:

- Fill materials
- Soft silt layer
- Sand layer
- Hard silt or clay layer.

4.3.1 Fill Materials

Below the ground surface, the site is immediately underlain by fill material. The thickness of this fill material ranges from zero to greater than 20 feet, and it is heterogeneous in composition. The fill consists of a random assortment of ore residue, silt, sand, gravel and rock, building debris, oyster shell fragments, ash, and wood. The occurrence of the fill materials is nearly continuous across the site. Cross Section C-C' in Figure 5 shows fill materials are absent in only the east-central portion of the site. Boring W-1, located behind the main office building, was the only boring installed by IT which did not encounter a readily identifiable near-surface layer of fill materials. Near-surface stratification of the sands encountered in W-1 was observed, but no other visual evidence was found which positively indicates this material is fill. Fill materials encountered in W-4 are comprised mainly of clean sands and gravel with small amounts of silt and clay; a composition which remained relatively uniform with increasing depth. These materials are apparently representative of the fill used in this portion of the site following the bulkhead extension on the plant's west shore in the late 1960s.

Many portions of the fill materials showed visual evidence of the presence of chromium. Bright, yellowish-green colors were frequently encountered in the coarser fill zones. Fill materials oftentimes reacted positively in the field with diphenyl carbazide, indicating the presence of hexavalent chromium. These reactions are noted on the boring logs presented in Appendix B. Fine-grained materials (possibly ore refuse) often imparted a dark green color to any free water encountered in these zones during drilling. Due to the depth of fill and the relatively shallow depth to ground water (approximately six to seven feet below ground surface), ground water at the site is in contact with fill materials. Results of soil and ground water analyses are presented in Section 5.3 of this report.

In general, the structural bearing capacity of the fill appears to be good. Most of the fill samples obtained during drilling were classified as medium dense to dense or medium stiff to stiff according to Standard Penetration Test criteria. As such, these materials would be expected to provide the necessary bearing capacity for most small structures. However, the fill's overall bearing capacity is decreased substantially in those areas where it is underlain by the soft silt layer which is described in the following paragraphs.

4.3.2 Soft Silt Layer

A layer of soft, black silty materials was frequently encountered immediately beneath the fill materials and was typically 10 to 20 feet thick. This layer is characterized by its uniform particle size (primarily silt with some clayey areas) and low bearing capacity. The silts are soft to very soft and in some instances appeared semiliquid. The layer is saturated in most areas since it lies at or below the site ground water elevation.

This silt layer was not encountered by IT in the central portions of the site, i.e., Drilling Locations W-1, B-1, and B-2. It is noticeably

absent in Cross Section C-C' in Figure 5. Boring W-4, located inside the area filled behind the new western bulkhead, also did not encounter the silt layer. Plant historical records revealed a series of borings which were installed in conjunction with construction of the present bichromate plant. Nineteen of these borings were located in the northern half of the plant, west of Point Street and between Block and Philpot streets. None of the 19 borings encountered the silt layer, including those which were located immediately west of the old bulkhead line (i.e., drilled in the harbor), in the area now covered by the western bulkhead. These boring logs and IT logs were used in constructing Figure 6, which gives an approximate representation of the areas beneath the site where the silt layer can be found. Figure 5 shows the silt layer is not present beneath the central portions of the site. Since it is present only along the northern, southern, and possibly the eastern bounds of the site, the silt layer would be expected to have little impact on ground water migration beneath the site.

Due to its very soft nature, the bearing capacity of the silt layer is minimal. Blow counts required for the split spoon sampler to penetrate this layer were very low, as shown in the boring logs in Appendix B. In several borings, fill materials were found to have migrated several feet into the soft silt layer. The southern half of the bichromate plant is built upon extensive piling which penetrates the silt, although the exact depth of most piling is unknown. Additionally, the southern harbor slips and a large portion of the level ground in the southern portion of the site are built upon pilings and platform decking as shown in Figure 6. One engineering report done in 1956 concerning the south properties noted past instances where two portions of piers on piles had suddenly collapsed, probably because the pilings were driven through the silt and only penetrated a minimal depth into the underlying sand. The report concluded that the soft silts apparently did not provide enough lateral resistance to provide for a stable structure.

4.3.3 Sand Layer

The entire site is underlain at depth by a sand layer which consists of fine to medium sands, with occasional coarse or gravelly zones, and numerous silty lenses. The sand layer lies at or near ground surface near the center of the site and was encountered at depths as great as 40.5 feet in the southeastern portion of the site. Most sand samples exhibited visual evidence of chromium contamination and/or reacted positively in the field with diphenyl carbazide, indicating the presence of hexavalent chromium. Results of analyses of these samples are discussed in Section 5.3 this report. Only in Borings W-9 and B-5 did the sand layer exhibit no visual evidence of chromium contamination.

The sands are very dense and oftentimes offered substantial resistance to sampling and drilling. Their bearing capacity as a single unit is expected to be high.

4.3.4 Dense Silt or Clay Layer

what is permeability

Four borings (W-1, W-2, W-3, and W-7A) were advanced through the sand layer until a very dense, fine-textured layer was encountered at depths between 30.5 and 43.8 feet. This material, interlayered with dense sands, was also encountered in Boring W-10. The layer is almost impenetrable with hollow-stem drilling equipment. It generally consists of white to pink to light gray clay or silty clay, and resembles the kaolin clays described in the literature as a member of the Patuxent Formation.

not drill This layer provides a barrier to downward migration of ground water beneath the site as it was normally only moist or dry. Little or no field evidence of chromium contamination was found in the samples obtained from the clay layer. Results of analyses of soil samples are presented in Section 5.3 of this report. *how little*

4.3.2 Table 1 presents the results of field permeability tests conducted in site monitoring wells. As shown in Table 1, three of the wells were screened in the near-surface soft silt layer, and the remainder were

screened in the underlying sand layer. The three wells screened in the silt layer (W-6, W-7A and W-8) indicate formation permeabilities in the range of 10^{-5} to 10^{-7} centimeter per second (cm/sec), with the average permeability of the three being 9.6×10^{-6} . The highest value of the three was found in W-7A, in the northwestern corner of the site.

1.3.3 With the exception of the W-3 test value, all permeability test values for the sand layer are in the range of 10^{-3} to 10^{-4} cm/sec. W-3 was screened in one of the siltier zones of the sand layer and yielded a corresponding lower permeability value. The average permeability value for the sand layer was found to be 8.4×10^{-4} cm/sec.

4.3.5 Ground Water Elevations

Water level measurements were made in the wells and, using well top elevations furnished by Allied, the site ground water contours were determined. Table 2 presents the well top and ground water elevations as measured in the site monitoring wells. Figures 7 and 8 present the site ground water table configuration at high tide and low tide conditions, respectively. Figure 7 shows that at high tide conditions, the ground water gradient across the site is generally less than two feet, with flow originating from the east and migrating to the harbor along the site's north, west, and south shores. Ground water beneath the site does not respond rapidly to changes in the harbor water elevation, as shown by the fact that the harbor water elevation in Figure 7 is higher than that for site ground water. Figure 8 shows the same basic direction of flow occurring while the harbor is at low tide, although site ground water elevations are lower than those observed at high tide.

In general, Figures 7 and 8 indicate site ground water is in contact with harbor waters. Ground water flows from the site and into or beneath the harbor, with gradients becoming slightly more pronounced when the harbor is at low tide.

5.0 REGIONAL AND SITE ENVIRONMENTAL QUALITY

5.1 ENVIRONMENTAL AND HEALTH EFFECTS OF CHROMIUM

Chemical speciation plays an important role in determining the fate of chromium in the environment. Conditions favorable to Cr^{6+} will generally keep chromium soluble and mobile while conditions favorable to Cr^{3+} generally lead to the precipitation and adsorption of chromium onto the geomedia.

Chromium occurs in nature principally as the trivalent (Cr^{3+}) ion, such as in chromite ore, although its valency ranges from Cr^{2-} to Cr^{6+} . Chromium in the hexavalent oxidation state (Cr^{6+}) is produced and used by Allied at the site for the manufacture of a wide range of industrial compounds. The tetravalent and pentavalent valencies are unstable and disproportionate to Cr^{3+} and Cr^{6+} in aqueous solutions. Thus, trivalent and hexavalent chromium were expected to be the two principal valencies of chromium present at the site.

Trivalent chromium is the most stable form of chromium present under most natural Eh conditions, especially where the pH is greater than 6.5. The reactions of Cr^{3+} in soils parallel, in many respects, those of iron and aluminum, as its ionic radius falls between the radii for these two elements (Reisenauer, 1982). The trivalent chromium ion generally complexes as $\text{Cr}(\text{OH})^{2+}$, CrO_2^- , and CrO^{3-} . However, at high pHs, it has a tendency to precipitate as a hydroxide or oxide. Carbonates and sulfide precipitates of trivalent chromium also form readily.

Cr^{6+} is fairly soluble in water and is always found as an oxyanion, commonly as H_2CrO_4^0 , HCrO_4^- , CrO_4^{2-} , and $\text{Cr}_2\text{O}_7^{2-}$. The ionic species of Cr^{6+} is dependent on the oxidation state (Eh) and pH of the environment. It is precipitated at pHs between 6 and 8, and highly soluble in all other pH ranges. Due to their negative charge and water solubility, Cr^{6+} oxyanions are not significantly attenuated by clays and are often

quite mobile (Bartlett and Kimble, 1976b; James and Bartlett, 1983). Hexavalent chromium is the valence state of most concern as an environmental contaminant since it is the valency which most commonly produces toxic reactions in sensitive species. Hexavalent chromium is generally best attenuated by reduction reactions which convert the chromium to a less mobile, lower valence such as trivalent.

Typically, such reduction reactions would be expected to take place in the organic-rich, clayey sediments found in the harbor floor surrounding the site. It has been demonstrated that organic matter and Fe^{2+} readily act as electron donors in reducing Cr^{6+} to Cr^{3+} , even at pHs above neutrality. Reduction of Cr^{6+} is normally accompanied by an increase in pH (Bartlett and Kimble, 1976b).

Theoretically, oxidation of Cr^{3+} to Cr^{6+} should occur at redox potentials normally found in well-aerated soils. However, an extensive soil incubation study (Bartlett and Kimble, 1976a) found no evidence of such oxidation, regardless of the level of chromium added, the original soil pH, or the imposed aeration, temperature, or time conditions. Later studies (Bartlett and James, 1979) found that Cr^{3+} will readily oxidize to Cr^{6+} in the presence of oxidized manganese, a condition prevalent in many field soils. Atmospheric oxygen was also found to oxidize small amounts of Cr^{3+} in a stirred suspension with the pH adjusted above 9.

The toxic effects of chromium are highly dependent upon several factors, including chromium speciation and concentration, species of organism, and duration and type of exposure. Most effects are manifested as growth suppressions or abnormalities, although certain Cr^{6+} compounds are considered carcinogenic or lethal to some organisms. Chromium is not known to have any mutagenic or teratogenic effects (U.S. EPA, 1978).

5.1.1 Effects on Microorganisms

Cr^{6+} concentrations of 0.03 to 65 parts per million (ppm) have been shown to inhibit the growth of fresh water algae, while 1 to 5 ppm in seawater has been shown to decrease photosynthesis in kelp (Gough, et al., 1979). Several microorganisms have exhibited toxic symptoms when exposed to Cr^{6+} concentrations as low as 0.05 to 5 ppm (U.S. EPA, 1978). Ross, et al. (1981), found 10 to 12 ppm of Cr^{6+} was toxic to soil microbes, and that some Cr^{6+} was reduced by the microbes. No toxicity due to Cr^{3+} was observed at similar levels, and it was estimated Cr^{3+} would only be toxic if applied at levels of 100 times or more of the Cr^{6+} toxicity levels.

5.1.2 Effects on Plants

The effects of chromium on plants are highly specific to the plant species and the chromium concentration. Interacting factors such as the content of other elements in the growth medium can affect the results (U.S. EPA, 1978). Most toxic symptoms due to excess chromium are due to chromium buildup in plant roots, with relatively small amounts translocated to other parts of the plant. Tobacco plants which exhibited chromium toxicity symptoms were found to contain 18 to 24 ppm chromium in leaves and 375 to 410 ppm in their roots (Gough, et al., 1979). Corn plants with as little as 4 ppm chromium in their leaves were found to exhibit toxic symptoms.

5.1.3 Effects on Animals

In animals, the effects of chromium have been primarily studied in aquatic species. There are no reported effects on birds or wild or domestic animals, but the data base is limited. In aquatic species, chromium toxicity varies with pH, water hardness, temperature, and species and size of organism. Toxic effects on some invertebrates have been reported at concentrations as low as 0.05 ppm chromium (U.S. EPA, 1978). In soft water, Cr^{3+} is more toxic to fish than Cr^{6+} , but in hard water the opposite appears true. Both forms are readily adsorbed onto

body surfaces. Cr^{6+} is accumulated by marine animals while Cr^{3+} is not. Adsorption and accumulation are passive mechanisms which are dependent upon the chromium concentration. Elevated chromium concentrations have been shown to cause several physiological changes in aquatic species, including growth reductions, decreases in hematocrit values and protein content, impairment of reproduction, and increased oxygen consumption (U.S. EPA, 1978).

Cr^{3+} and Cr^{6+} behave differently in aqueous systems. Cr^{3+} added to fresh water systems (added as chromic chloride) results in hydroxide formation and precipitation. The particles formed readily adsorb to surfaces. Chromium's ability to form carbonates and the adsorptive ability of Cr^{3+} make these compounds common components of clam and oyster shells in chromium contaminated marine environments. One study found chromium content in shells was more than 1,000 greater than that in the study area seawater (U.S. EPA, 1978). Cr^{6+} compounds in aqueous systems form true solutions containing no particulate matter. In oxygenated natural waters with high alkaline values, chromate species are quite stable.

The U.S. EPA has established the following chronic and acute exposure dosages for Cr^{3+} and Cr^{6+} in aquatic environments:

	<u>Chronic</u> (mg/l)	<u>Acute</u> (mg/l)
Cr^{3+}	-	5,150
Cr^{6+}	18	1,260

The acute dose of 5,150 milligrams per liter (mg/l) for Cr^{3+} is not an established criterion. Rather, it is the concentration lethal to 50 percent of the sample population (LD_{50}) for the most sensitive species tested (striped bass larvae). The LD_{50} for rats injected with Cr^{+3} was found to be 1 milligram per 100 grams of body weight. No toxic effects were seen if the Cr^{+3} was given orally.

5.1.4 Effects on Humans

In humans, chromium is an essential trace element. Most uptake is through ingestion with ingested Cr^{6+} reduced to Cr^{3+} by acid gastric juices. Lesser amounts are introduced to the human body by the respiratory tract and through damaged skin. Exposure to chromates may cause primary irritations with ulcers and nonulcerative contact dermatitis. A higher incidence of lung cancer has been associated with long-term exposure to Cr^{6+} dusts and mists, with a latent period between first exposure and occurrence of cancer of between 10 and 20 years.

The toxic level of chromate to humans is 270 ppm, and the lethal level is 4,000 ppm (Gough, 1979). Levels as low as 30 milligrams per cubic meter (mg/m^3) of airborne chromic acid or chromates have been found to be immediately dangerous to life or health (U.S. Department of Labor, 1978).

5.2 EXISTING REGIONAL AND SITE ENVIRONMENTAL QUALITY DATA

5.2.1 Inner Harbor Region

5.2.1.1 Ground Water

Only limited data could be obtained which characterize regional ground water quality. Data were obtained for four wells in areas to the northeast and northwest of the site utilized by the USGS in a recent study concerning a proposed bridge location near Fort McHenry. The well locations are shown in Figure 9 and the results of analysis of ground water samples obtained from these wells are presented in Table 3. These data show little or no chromium was found in ground water at these locations. Elevated levels of barium and iron were common, however. It is not certain what formation these wells are screened in, but they are located in or near surficial outcrops of the Potomac Group.

5.2.1.2 Harbor Water and Sediments

An extensive study (U.S. EPA, 1977) was recently completed which evaluated the effects of pollutants currently in place in the Baltimore Harbor. As part of the study, concentrations of several heavy metals, including chromium, were determined for samples of the harbor water, sediments and their interstitial waters, elutriates prepared from the sediments, and bioassay samples. The study generally found pollutants were in high concentrations throughout the harbor, with biota in the harbor being stressed by the in-place pollutants. The sources of the pollutants were determined to be waste discharges which have become incorporated into the sediments. Various remedial action concepts were evaluated, with the favored alternative being leaving the pollutants in place, as it was felt that removal of contaminated sediments would only be a temporary solution as long as industrial discharges continue to reach the harbor.

*Need
Map and
more detail*

This same study utilized 20 sampling locations in the harbor, ranging from immediately south of the Allied plant in the Inner Harbor to points as far southeast as Rock Point and Rock Creek. Although significant concentrations of pollutants were found at all sampling locations, the concentrations of most contaminants, including chromium, were found to decrease somewhat with increasing distance from the Inner Harbor. The first three sampling locations, which were located in or near the Northwest Harbor Branch, contained the highest levels of chromium of the 20 sampling locations, ranging from 1,037 to 1,848 ppm total chromium in sediments. These values are generally higher than most of the chromium values for sediment samples obtained from areas adjacent to the plant and analyzed by IT. Results of these analyses are presented in Section 5.3 of this report.

Table 4 summarizes the analytical data for the sampling station utilized by EPA which was nearest to the Allied facility. Results for sediment analysis are in milligrams per kilogram (mg/kg) while results for interstitial and harbor waters are presented in micrograms per liter. As

shown, the harbor contains significant concentrations of metals in both sediments and water, but the sediments are acting as a primary repository for metals. Total hydrocarbon content is quite high, and several studies mention the oily residue commonly found on the harbor sediments and biota. Chromium concentrations at depth in the sediment at the sampling location nearest Allied averaged 1,115 mg/kg (at 0.5 feet) to 130 mg/kg (at 10 feet). As shown in Table 4, markedly less amounts were found in the water samples, indicating the chromium is largely immobile. Somewhat higher amounts of chromium were found in those harbor water samples obtained by IT during this study. These are discussed in Section 5.3 of this report.

Similar results were found in less comprehensive, unpublished data obtained from the USGS, the MGS, and the U.S. COE. These data show total chromium values in sediments as high as 2,000 to 4,100 mg/kg in the Inner Harbor region, with values declining to approximately 500 mg/kg just south of Ft. McHenry, and eventually dropping to less than 100 mg/kg where the Patapso River empties into the Chesapeake Bay east of Rock Point.

5.2.2 Site-Specific Data

5.2.2.1 Ground Water

In 1973, Allied drilled 15 borings to a depth of 18 feet to investigate potential underground seepage beneath the roadway at the southeastern corner of the bichromate plant, near the south slip. Some subsidence had occurred in this area, which prompted the drilling program. Water samples were obtained from these borings and analyzed for total chromium and pH. The pH values were all quite alkaline, ranging from 9.2 to 11.7. Chromium concentrations ranged from 31 ppm to nearly 2,800 ppm, with the highest value found near the area of subsidence. Chromium was generally highest in those borings located nearest to the plant. No mention is made of the ground water level in these borings.

Eight borings were also drilled around the perimeter of the plant in 1972 to investigate potential leakage through the bulkheads. Water samples were collected from the borings and analyzed for Cr^{6+} content. Measurements were made periodically of the water levels in the borings and in the adjacent harbor. Cr^{6+} concentrations in water samples collected from the borings were found to average approximately 2,500 ppm, and ranged from 20 to 19,300 ppm. The study found little correlation between harbor levels and ground water levels in the borings. The depth of the borings is unknown, although it is likely the borings did not fully penetrate the soft silt layer beneath the site; water level would be expected to fluctuate slowly in this case. The only location which exhibited any direct water level fluctuation with the harbor was along the south shore, west of the south slip. This location also had the lowest Cr^{6+} concentration, indicating dilution with harbor waters may have been active.

5.2.2.2 Harbor Water

Allied has obtained harbor water samples from around the plant bulkhead at various times to monitor their cooling water discharges for National Pollutant Discharge Elimination System (NPDES) permit compliance. These outfalls are currently permitted to discharge approximately four pounds of Cr^{6+} per day.

Additionally, water samples have been collected at several points in the Inner Harbor by Allied on irregular intervals since 1966, with the most recent samples obtained in 1982. Samples were analyzed for Cr^{6+} only. The 1966 values ranged from 0.051 mg/l Cr^{6+} to a high of 0.301 mg/l at the gap in the northwest shore bulkhead, near the old Koreon™ unit. However, little is known about the methods through which these data were obtained in 1966, and Allied now considers these data suspect. Values for all sampling locations except one increased significantly when analyzed again in 1970, with the highest concentration of Cr^{6+} (1.396 mg/l) found along the west shore, near the southwestern corner of the

bichromate plant. In 1972, additional sampling locations were added to the program, extending the sampling locations as far as Ft. McHenry. All sampling locations but one showed significant decreases in Cr^{6+} content over the 1970 data, with the highest value found being 0.140 mg/l Cr^{6+} outside of the outfall at the 001 cooling water outfall. The newer sampling locations further downstream from the plant all contained approximately 0.010 mg/l Cr^{6+} .

Data for 1981 showed mixed results, with some sampling locations showing increased Cr^{6+} content while others decreased. The highest level observed at this time was 0.721 mg/l Cr^{6+} at the gap in the northwest shore bulkhead near the old Koreon™ unit. Most of the samples obtained from the southern end (mouth) of the Inner Harbor had no detectable Cr^{6+} .

The 1982 data show substantial increases in harbor water Cr^{6+} content around the plant. South of the City of Baltimore's Pier No. 7, Cr^{6+} has increased by nearly an order of magnitude to 0.704 mg/l. The highest levels adjacent to the plant were found in the two samples obtained from the Back Basin north of the plant (0.943 and 0.622 mg/l). These sampling locations have historically indicated high Cr^{6+} concentrations. The 1982 sampling program also obtained samples at varying depths at a few locations. Cr^{6+} concentrations at these locations decreased with increasing depth.

5.3 RESULTS OF SITE ENVIRONMENTAL QUALITY INVESTIGATIONS

5.3.1 Soil Samples

The results of analyses of the various soil and sediment samples collected by IT are presented in Tables 5 through 9. The findings have been arranged such that the results for each stratigraphic layer encountered beneath the site are presented on separate tables.

5.3.1.1 Fill Materials

Table 5 presents the results of analyses of samples taken from the layer of fill materials which lies at ground surface over most of the site. The results show this layer is high in iron and generally high in chromium content. Total iron in these fill samples ranged from 4,900 to 31,000 ppm. Total chromium content ranged from 25 to 34,000 ppm, but generally averaged about 4,000 ppm. Hexavalent chromium values ranged from none detected to 2,900 ppm. Chromium values generally corresponded with the proximity of the sampling location to either current or historic production facility locations. Some of the highest total chromium values were found in the vicinity of the old bichromate plant, the special products facility, and the refuse storage and handling facilities. The highest total chromium value (34,000 ppm) was found in the center of the area formerly occupied by the old bichromate plant (W-10). In most instances, samples with relatively high total chromium concentrations contained only a small percentage of total chromium in the hexavalent form. Such samples frequently contained high amounts of barium and also corresponded with areas known to have been backfilled with ore residues. This may also indicate subsurface conditions at these locations are favorable for the formation of the less-mobile trivalent chromium species. Areas known or suspected to have been filled with ore refuse include the southern shore and the old bichromate plant locations, two areas whose fill layer samples have high total chromium contents and much smaller concentrations of hexavalent chromium. Additionally, the fill layer sample from the northwest corner of the site (W-7A) near the special products unit also contained a significant concentration of chromium. The early aerial photographs of the site indicate some backfilling operations probably took place here at least during the late 1930s, but it is not certain that ore residues were used as backfill here. Drilling at W-7A did not indicate the presence of a substantial depth of fill materials, as shown in the boring log contained in Appendix B.

The near-surface sample from W-1, near the center of the site, was found to contain a significant concentration of total chromium (6,200 ppm), with approximately 5 percent of this being in the hexavalent form. This sample also yielded the highest levels of all soil samples of total and hexavalent chromium as determined by the EP Toxicity leachate test. No apparent fill materials were observed here, although some near-surface stratification of the sands was observed, indicating some coarse, thin fill deposits may be present. Materials in the upper two feet at W-1 contain significant quantities of visible chromium. Plant records indicate this area was once used for ore storage and that an area of ore residue "test strips" was installed immediately east of the location.

Only 5 of the 15 fill layer samples analyzed exceeded the EP Toxicity test threshold value for chromium. No other EP Toxicity metal thresholds were exceeded. The threshold values for metals used in determining whether or not a material is considered toxic are presented in Table 10. The threshold value for total chromium is 5 ppm. As stated previously, the fill layer sample from W-1 contains significant amounts of leachable total and hexavalent chromium (270 and 215 ppm, respectively). The other fill layer samples which yielded chromium values in excess of the EP Toxicity test criteria were the samples of fill from the northeastern corner of the site (W-2 and W-10) near the old bichromate plant and the location immediately south of the refuse bin (W-6).

5.3.1.2 Soft Silt Layer

Results of analyses of samples from the soft silt layer are presented in Table 6. This layer lies immediately below the fill layer but is absent in the central portion of the site. As with the fill layer samples, these samples also have high iron values. EP Toxicity test threshold values were exceeded only for chromium. Total chromium values were generally lower in the 13 soft silt layer samples than in the overlying fill layer. However, two of the highest total chromium values observed in this study were found in the soft silt layer. A total chromium value

of 24,000 ppm was found in this layer north of the special products facility (W-3), while a value of 16,000 ppm was found at a depth of 33.5 to 35 feet in the boring south of the refuse bin (W-6). These same two samples were the only silt samples to exceed the EP Toxicity test threshold for chromium. As with the fill layer samples, only a small percentage of the total chromium observed in the soft silt samples is in the hexavalent form. Most samples contained no detectable hexavalent chromium. The soft silt sample from W-6 had the highest barium content observed in this study (480 ppm), but it did not exceed the threshold value when the sample was leached according to the EP Toxicity test.

The location of Boring W-3 was established along the northern bulkhead, north of the special products plant, after the diver's bulkhead evaluation had revealed a discolored liquid leaking into the harbor at this location. Discoloration was observed at depth in this boring and in ground water samples obtained from this monitoring well. Results of analysis of the ground water samples are presented in Section 5.3.2. It is our understanding that Allied has determined the discolored, strongly acidic liquid encountered here contains Koreon™, a chrome sulfate product utilized by the leather tanning industry. This product was commonly manufactured at the Baltimore Chrome Works in the past, but now is manufactured only infrequently at the site. The presence of Koreon™ contamination would explain the very high sulfate and total chromium values and low pH and hexavalent chromium values found in the soft silt at W-3.

5.3.1.3 Sand Layer

The sand layer beneath the site generally contains lower concentrations of chromium than either the overlying silt or fill layer, as shown by the results of analyses of sand layer samples in Table 7. Many of these samples contained less than 100 ppm total chromium and only minor concentrations of hexavalent chromium. Exceptions include samples from the center of the site (W-1), samples from north of and near the center of

the old bichromate plant (W-2 and W-10), and samples from the northwest corner of the site (W-7A) and west of the current bichromate plant (W-4). Samples from these locations exceeded the chromium threshold value when analyzed by the EP Toxicity test, with most present in the hexavalent form. Additionally, the sand layer sample analyzed from the north shore (W-3) was found to contain 1,600 ppm total chromium, yet had no detectable hexavalent chromium. Similarly, this same sample exceeded the EP Toxicity test threshold value for chromium but released no detectable hexavalent chromium when leached. Apparently, the highly acidic nature of the product encountered here (pH of 0.6) is favoring the reduction of chromium to the less mobile form, with the actual reduction being caused by the presence of iron or some other electron donor. Alternatively, Cr^{6+} may have never been present here.

As with the previously discussed results of analyses, sand layer samples did not exceed any other EP Toxicity test threshold values than that for chromium. Also, the iron content of the sand layer samples was generally lower than those of samples from the overlying strata.

5.3.1.4 Hard Clay or Silt Layer

Five samples were obtained from the deep, dense hard silt and clay layer found beneath the site at depths ranging from approximately 30 to 45 feet. These samples exceeded no EP Toxicity test threshold values except that for chromium, as shown in Table 8.

*what is limit
of clay?*

The samples from this dense layer from Borings W-1 and W-2 contained significant quantities of total and hexavalent chromium and exceeded the EP Toxicity test threshold value for chromium. These concentrations were, however, somewhat less than those found in overlying layers in the same borings. Based on the results of analyses of samples from this dense layer and field observations of its density, resistance to drilling and sampling, fine texture, and low moisture content, it is likely that the upper portion of this layer represents the maximum depth of

chromium contamination beneath the Allied site. Lesser amounts of chromium were detected in the samples from this layer taken from Borings W-3 and W-7A. Little or no chromium was detected in the EP Toxicity leachates for W-3, W-7A, and W-10 samples from this layer. The elevated total and hexavalent chromium concentrations found in this layer at W-1, W-2, and W-10 are believed to be the result of high mass loading of the geologic system, with chromium at these locations resulting in some contamination of the upper (penetrable) portion of this layer. Chromium contamination would be expected to decrease rapidly with depth in this layer at these locations, as it apparently does in the other locations where little or no chromium was detected in this layer.

5.3.1.5 Harbor Sediments

Results of analyses of the three harbor floor sediment samples collected at points adjacent to the site are shown in Table 9. The results show that chromium is present in the harbor, as values range from 170 to 1,800 ppm total chromium and from 2 to 13 ppm hexavalent chromium, with the highest concentrations found in the sample from the Back Basin north of the plant (S-3). These values are generally lower than those presented in existing regional data, as was discussed in Section 5.2. No total or hexavalent chromium was detected in the EP Toxicity test leachates of the harbor sediment samples. The harbor sediments apparently provide an effective reducing environment for hexavalent chromium and further provide ample exchange sites for immobilizing the trivalent form. This is further evidenced by the negative Eh measurement values in Table 9, indicating effective reduction capability.

In summary, significant concentrations of total and hexavalent chromium were found in fill layer materials at the site, as well as in underlying strata from borings near the bichromate plant, the special products facility, the ore refuse bin, the old bichromate plant site, and the central portion of the site. Hexavalent chromium generally comprised no more than 5 to 10 percent of the total chromium concentration and, other

than chromium, no other EP Toxicity test threshold values were exceeded. Chromium contamination of the strata beneath the site decreases with depth and probably does not penetrate below the upper portion of the dense, silt/clay layer. Harbor floor sediments contain lower but elevated concentrations of chromium, and likely provide a reducing environment capable of immobilizing chromium. Chromium was not detected in the boring immediately east of the plant property (B-5), and only minor amounts were found in samples from W-9, located in the southeastern corner of the plant property.

Sample S-9 (21 to 22.5 feet) from Boring W-4 was observed in the field to have a noticeable "mothball-like" odor. This sample was collected at the depth where the fill materials placed behind the western bulkhead extension were fully penetrated. These materials consisted of clean clayey sands and gravel. This sample was analyzed by GC/MS for base-neutral extractable priority pollutants in an effort to identify the source of the noticeable odor. Results of analysis are presented in Table 11. These results reveal the sample contains detectable quantities of a related group of compounds, including acenaphthene, anthracene, benzo(a)anthracene, benzo(a)pyrene, various fluoranthene compounds, chrysene, fluorene, naphthalene, phenanthrene, and pyrene. These polynuclear aromatic hydrocarbon compounds are common components of coal tars. There is no apparent on-site source of these organic compounds. Their presence may indicate previous contamination of the harbor sediments which were buried by the fill materials or that contaminated fill materials were obtained from off site. A thin layer of wood was penetrated just above the depth at which this sample was obtained (see boring log in Appendix B), making the possible presence of coal tar-derived wood preservatives the most likely explanation for the presence of these compounds.

2-1 coal, shales, sulfates, and lignite present until 20 ft.
2-2 In coal just present still with small amount of 20 ft.

5.3.2 Surface and Ground Water Samples

Tables 12 through 14 present the results of analyses for surface and ground water samples obtained from borings, monitoring wells, and the harbor. Sampling locations are shown in Figure 2.

The general chemistry parameters shown in Table 12 indicate most water samples are somewhat alkaline with no potential acidity and abundant alkalinity. The one exception is the ground water sample from W-3 which is highly acidic. Ground water samples were generally found to have appreciable concentrations of chloride, sulfate, and dissolved residue. Harbor water samples (S-1, S-2, and S-3) also contained significant concentrations of these parameters, particularly chloride. Hexavalent chromium was detected in only one of the harbor water samples (S-3) and ranged from none detected to 7,500 mg/l in the ground water samples. The highest amounts were found in the deep well (W-7B) at the northwest corner of the plant property and in the well immediately west of the bichromate plant (W-4). Lesser concentrations but in excess of 1,000 mg/l hexavalent chromium were found in Well Nos. W-1, W-2, W-6, and W-7A. No hexavalent chromium was detected in W-3, indicative of the highly acidic conditions found here. However, high concentrations of sulfate (80,000 mg/l), total organic carbon (1,200 mg/l), and total chromium (9,200 mg/l) were detected in W-3. With the exceptions of B-2, B-3, B-5, W-5, W-8, W-9, and W-10, all ground water samples contained greater than 1,000 mg/l total chromium.

It must be noted that the high chromium content of the ground water samples presented some difficulties in analyzing these samples by standard accepted methodologies. Most U.S. EPA-approved analytical techniques are designed for detection of a suspected pollutant in concentrations near that where certain environmental impacts are realized (e.g., threshold limit value, IDLH, or drinking water standard values). These methodologies were not designed to quantify high concentrations of these pollutants. As such, IT found it necessary to dilute many of the water

samples in order to bring the chromium concentrations of the aliquot within standard limits. When these values were then multiplied by the dilution factors to provide a total sample value, some dilution factor-induced errors were realized which cause the hexavalent chromium concentration to appear slightly greater than the total chromium concentration of many ground water samples. Table 15 presents the dilution factors which were necessary to complete the total and hexavalent chromium analyses. The samples with the larger dilutions are subject to the greatest amount of analytical error. The values for hexavalent and total chromium, however, are generally quite close for most ground water samples, indicating most, if not all, of the chromium in the ground water beneath the site is in the hexavalent form.

Sodium was the only other metal found in the ground water samples in high concentrations. It was detected in significant concentrations in most of the same wells where high chromium was detected. This fact, coupled with the locations of the wells, suggests leakage from production facilities has contributed significantly to ground water contamination, although the presence of buried ore refuse may have the same effect in degrading ground water quality.

The metals found in the harbor water samples (Table 14) consisted primarily of calcium, magnesium, potassium, and sodium; normal constituents of salt water systems. Minor amounts (less than 1 mg/l) of chromium were found in Samples S-1 and S-2, while Sample S-3 contained 14 mg/l total chromium and 12 mg/l dissolved chromium, of which 7.5 mg/l is in the hexavalent form.

5.4 OFF-SITE CHROMIUM MIGRATION

Ground water contour gradients indicate ground water flow at the site is toward the harbor to the north, west, and south. Results of analyses of site ground water samples have revealed significant concentrations of hexavalent chromium present beneath the site. The diver's bulkhead

inspection revealed areas of leakage into the harbor, particularly along the northern bulkhead, and chromium was found in the harbor water and sediment samples collected in this area. With these indications that some chromium is migrating off site, an attempt was made to quantify the amount of chromium leaving the site daily.

A series of mass loading calculations (MLC's) were performed by IT in order to quantify the amounts of off-site chromium migration. The site was divided into eight sectors (Figure 10), each containing one monitoring well along the plant's perimeter, with all sectors converging on Monitoring Well W-1, the well with the highest ground water elevation as measured by IT and conveniently located near the center of the site.

Basically, the MLC process consists of calculating chromium migration within each sector based on the area of each sector (including aquifer thickness), the difference in gradient between W-1 and the perimeter well in each sector, the distance between W-1 and the perimeter well, and the total and hexavalent chromium concentrations in ground water at each of the perimeter wells. Flow per day (Q) through each sector was determined using the following equation:

$$Q = KIA$$

where K is the permeability value for the aquifer at each well as determined by the rising head tests conducted on site, A is the area (square feet) of the sector as viewed in a cross section intersecting the perimeter well location and perpendicular to the direction of flow, and I is defined as follows:

$$I = \frac{\Delta h}{l}$$

where Δh is the difference in ground water elevations between W-1 and the perimeter well in each sector, and l is the distance between the two

wells. These calculations were made for both high tide and low tide conditions and the results averaged to present values on a daily basis. This assumes high tide and low tide conditions prevail equally on a daily basis.

These calculations revealed that approximately 2,300 gallons per day of ground water pass beneath the site, discharging either into the harbor or beneath the harbor floor through the aquifer layer. The greatest migration occurs during low tide, and the greatest volume of flow appears to be through the southern portion of the plant (Sector G as shown in Figure 9).

Once the high tide and low tide ground water flow rates were determined, the amount of chromium (Z) carried by the migrating ground water was determined according to the following formula:

$$Z = Q (\text{low tide, high tide}) \times C$$

where C equals the total or hexavalent chromium content of the ground water sample obtained from the perimeter well in each sector. Where hexavalent chromium values were larger than total chromium due to multiplicative error associated with the sample dilution factors, the values were reversed for consistency for the purposes of these calculations.

The results of the MLC's are summarized in Table 16 and indicate that approximately 25 pounds per day of chromium is migrating from the site; approximately 80 percent of this is in the hexavalent form. As shown in Table 16, Sector D appears responsible for the majority of the contaminant migration. This sector includes Monitoring Well W-4, located west of and downgradient from the bichromate plant. The large amount of chromium migration revealed here by the MLC is due not only to the large amount of chromium detected in W-4 but also to the large cross-sectional area at W-4 utilized in the MLC's. While Boring W-4 only penetrated the

sand layer by five feet at this location, existing boring logs indicated a sand layer thickness of 17 feet in this area. This larger figure was used in the MLC's and thus gives more significance to the large chromium concentrations found in W-4.

6.0 SITE BULKHEAD INTEGRITY AND STORM SEWER INVESTIGATIONS

6.1 SITE BULKHEAD INTEGRITY EVALUATION

Allied has periodically had underwater inspections made of the bulkhead surrounding the plant. The most recent of these was conducted in the fall of 1984, with IT providing some input and direction, particularly concerning areas of leakage or residue buildup as observed by the diver. Copies of underwater inspection reports for 1958, 1970, 1971, 1978, 1980, 1982, and 1984 were made available to IT. Some of these were for inspections of only a portion of the bulkhead. Indications are that other inspections have been conducted, but no other diver's reports were found. The results of the 1984 inspection are summarized in Figure 11.

The bulkhead is constructed primarily of wooden sheet piling capped with either a concrete, stone, or timber bulkhead. Some steel sheet bulkheads have been installed along the western corner of the south slip, the new western shore (steel sheet cells), and a small area west of the tank farm. The structural condition of the bulkheads varies.

The bulkhead area in poorest condition is the northwestern corner of the plant property in an area approximately 50 feet south and east of the northwest corner of the bulkhead. This area has historically been settling, with small cracks and cavities currently visible at the ground surface. A large gap in the surface cap of the bulkhead has developed along the western shore and has been migrating northwest since at least 1971. The latest diver's report states the entire area under water "appears near failure." The underlying timber work here is reported to be in very poor condition, with several sizeable fill leaks and voids noted. Pile angles were off as much as 15 degrees and sheeting angles off as much as 18 degrees. Piles and caps were found to be out of place or with poor bearing and loose or missing wedges. This condition was first noted in the 1971 diver's report and has gradually worsened, according to subsequent diver's reports.

*historical
potential
release
area*

Other locations around the bulkheads have been reported deteriorating or leaking fill materials at various times, but most have been minor and repairs installed soon after notation of the problem. In 1980, a section of the decking over the covered slip in the southwestern portion of the site was found missing and a milky liquid observed leaking into the underlying harbor and spreading across the bottom. This was repaired and has appeared in good condition in subsequent inspections. Several other minor leaks and repairs have been noted in the older diver's reports, although no special emphasis was placed on locating leaky areas until the latest inspection took place.

The Bowie Smith pier has historically been determined to be structurally sound, as it was once again in 1984. No significant deterioration of the pilings or pile caps has occurred here. In the south slip area, numerous small holes were reported in the bulkhead approximately two feet below the water line and some piping of materials is occurring through the holes. Sizeable gaps in the sheeting wall along the southwestern corner of the plant bulkhead were found in this most recent inspection. Numerous small traces of a hard white residue appeared in this area on joints or splits in the sheeting, but there was no deposition of these materials at the base. The diver found the west shore steel sheet cells to be in good condition, but again noted a large deposit of the white residue where the steel sheeting joins the old wood sheeting to the north. Samples of these materials were obtained and subjected to X-ray diffraction and energy dispersive analyses. Results of analyses are presented in Tables 17 and 18. These materials consist primarily of chromium, calcium, and magnesium carbonate minerals. The crystalline structure of these materials was found to be dependent upon their moisture content, as shown by the results of the sample which was heated to 105 degrees Centigrade (Table 17). Cr^{3+} is being incorporated into the carbonate structure and is thus immobilized.

Two water samples were obtained by the diver along the western bulkhead where the residue was observed, and a sediment sample was obtained in the same area at the bottom of the piling where residue was accumulating. The sediment sample contained some residue. Results of analyses are included in Tables 19 and 20. Results of analyses of the water samples (Table 19) show the samples are alkaline with a high redox potential (high Eh) and with conductivity and chloride values representative of salt water. Significant concentrations of total chromium are present, with a slightly higher concentration found in the bottom water sample, taken at the base of the pilings. Lesser concentrations of hexavalent chromium were found (8.4 and 2.4 mg/l), with the smaller concentration found in the bottom sample. These values are less than those reported in the regional data, as discussed in Section 5.2.1. The volume of the sample from the north shore was insufficient for detailed analysis.

The west shore bottom sediment and residue sample was analyzed for total metals and metals extractable by the EP Toxicity test procedure as shown in Table 20. Total chromium and hexavalent chromium were found in concentrations of 12,000 and 8,200 mg/l, respectively. These values are higher than most of the values reported in regional data for total and hexavalent chromium content of harbor sediments. Significant quantities of total and hexavalent chromium were also found in the sample's EP Toxicity leachate.

The bulkhead along the plant's north shore was found by the diver to be in good structural condition, with the exception of the westernmost 50 feet as discussed previously. However, several areas of brittle white residue and discolored liquid leaks were observed along the north bulkhead. The liquid leaking through the bulkhead had a reddish-orange color and was noted by the diver in at least three separate locations. A small sample was obtained by the diver and a limited analysis of the sample was conducted. Results are included in Table 19 as the North

Shore sample. Chloride and conductivity values were representative of salt water, and the sample was found to contain a small concentration of organic carbon. The pH value (5.10) was somewhat lower than other values observed in the harbor, indicating some acidic compound is lowering the pH at the point of leakage.

In summary, the bulkhead appears to be structurally sound with the major exception being the northwest corner of the site and the areas of leakage along the north shore. The northwest corner is gradually deteriorating, as slippage and subsidence have been observed here for several years. The ground water monitoring well screened in the silt layer here (W-7A) had a slightly higher permeability than other site wells screened in similar materials, indicating a zone of increased permeability may have been created here by the movement of the bulkhead. The earliest aerial photograph of the site (Figure A-1) revealed the possibility that this corner of the site may have been extensively backfilled; piling in this area may not be in contact with firm, natural strata.

6.2 SITE STORM SEWER EVALUATION

Site storm sewers were located using drawings supplied by Allied. Additionally, this information was checked against records held by the City of Baltimore, Public Works Department. Using this information, the locations of all recorded storm sewer surface inlets were checked in the field during a rainstorm and an evaluation made of their ability to accept surface runoff. Also, the storm sewer outlets were inspected underwater by the diver while evaluating the bulkhead integrity. The locations and condition of the storm sewers are presented in Figure 12.

Most surface inlets are either plugged or were paved over and could not be found. Some flow was noted in the drains along the western end of Block Street which flow into the 001 cooling water discharge. Most other surficial inlets on site were plugged at or near ground surface or, if open, showed no evidence of flow. A few of the near-surface

plastic plugs were found to be damaged in the southern end of the site and may be allowing some surface runoff to enter the system. These are noted in Figure 12.

The diver's observations were quite valuable in determining which storm sewers are carrying runoff or leakage into the harbor. With the exception of the two plant cooling water discharges and the small weep pipe near the intake, one outlet leak was observed and several abandoned but plugged drainage outlets were discovered along the bulkheads.

Beginning along the plant's southern shore, the diver noted one outlet along the southwestern bulkhead currently has some cracked mortar and loose brickwork around the outlet, indicating some potential for leakage in this location. The drain nearest the south slip was not observed leaking, but no harbor plug was present. Site conditions prevented access to the drain located inside the south slip.

The inspection of the north bulkhead in the Back Basin revealed the existence of several outlets not indicated on either the City of Baltimore's or Allied's records. A total of nine drain outlets were found here by the diver. Four of these have no near-harbor plug and a green liquid was observed discharging from one of these. Additionally, the diver noted at least three active bulkhead leaks along the north bulkhead in locations other than the drain outlets. These leaks were reddish-orange in color as previously discussed in this section.

In summary, it appears that most of the site storm drains indicated by either city or Allied records are plugged either at the surface or at the harbor. Some surface runoff enters a series of active storm drains along Block Street and enters the harbor along with a cooling water discharge. Only one drain was observed actually leaking into the harbor, in an area where other leaks coming through the bulkhead were observed by the diver. A few of the storm sewer plugs are in poor condition,

indicating some small amounts of flow may be exiting these storm sewers. Generally, it appears that site storm sewers are not acting as a major conduit of off-site contamination migration.

7.0 STUDY CONCLUSIONS

X Ground water beneath the majority of the Allied site is presently contaminated by significant concentrations of chromium, the majority of which is in the hexavalent form. The ground water concentrations of chromium encountered were higher than that which the soils at the site would be expected to release into the ground water system, according to EP Toxicity leachate tests. Both soil and water samples were generally higher in chromium where collected from borings or wells located near the old or current bichromate plants, the special products unit, or the ore refuse handling area south of the bichromate plant.

The ground water measurements made on several occasions by IT indicate ground water flows from the east, passes beneath the site, then discharges into or migrates beneath the harbor to the north, west, and south. Although Monitoring Well W-1 normally had one of the highest ground water elevations, it also had a very high chromium concentration for which the only discernable upgradient source may be two ore refuse "test strips" which were in place some time ago. Levels of chromium similar to that found in W-1 were found in other site wells which were downgradient from production facilities or the old bichromate plant site. Since no other wells exist between the current bichromate plant and W-1, the possibility exists that substantial ground water recharge is occurring through the bichromate plant leach area, causing site ground water elevations to be highest beneath the bichromate plant, thus allowing flow to W-1 to occur. This cannot be confirmed without an additional well immediately east of the bichromate plant, but would not be inconsistent with the data collected from the surrounding wells and borings.

Y Chromium is present in much of the fill layer which overlays most of the site. The soft silt layer found beneath the fill along the site perimeter has somewhat lower chromium concentrations and the underlying sand

generally contained even less. A very dense silt or clay layer was encountered at depth beneath the site and, while some of the samples from the upper portion of this layer revealed some chromium contamination, it is likely this layer represents the maximum depth of chromium migration beneath the site.

The storm sewer system on site appears to be adequately plugged and is not acting as a major conduit for off-site chromium migration, although one storm sewer discharge was observed leaking a discolored liquid and the seals at other locations may be in need of some slight repairs. The bulkhead surrounding the site is generally in good structural shape with some areas observed leaking either fill or discolored liquid. The most notable leaks were along the northern bulkhead, where several small discolored leaks were observed by the diver. This prompted the relocation of Monitoring Well W-3 in this vicinity, which encountered a quantity of a highly acidic chromium sulfate liquid. This is apparently the same material observed leaking into the harbor.

The northwest corner of the site bulkhead is apparently in very poor condition. The diver noted several structural defects in the bulkhead in this area. The surficial effects of this deterioration are beginning to become apparent, as subsidence, cracking, and movement of the pavement and bulkhead cap have been observed here for the past several years. Historical aerial photographs revealed uneven backfilling beyond the current bulkhead line in the late 1930s, and well permeability testing revealed the silt layer in this area is approximately one order of magnitude more permeable here than at the other locations on site where this layer was tested, indicating some zones of increased permeability exist here, possibly created by fracturing of the silt layer by bulkhead movement.

Ground water chromium concentrations are quite low to the east of the site (B-5), but are somewhat elevated in the southeastern corner of the

plant property (W-9). The high chromium and sodium concentrations found in the vicinity of the plant production facilities indicate that leakage within the manufacturing facilities has contributed significantly to site ground water contamination. Significant contamination can also be found in the vicinity of the old bichromate plant location.

MLC's indicate approximately 25 pounds per day of chromium is leaving the site via ground water either discharging into the harbor or migrating through the aquifer beneath the harbor floor. Approximately 20 pounds per day of the total chromium migrating from the site is in the hexavalent form. Harbor sediments apparently provide an effective environment capable of immobilizing hexavalent chromium, as indicated by the results of analyses of samples taken at points surrounding the Allied site. Some accumulation of chromium in the sediments surrounding the plant was observed, the majority of which was in the trivalent form. Chromium levels in sediments around the plant bulkhead were generally less than those levels reported in regional data for the Inner Harbor. Exceptions were the sediment sample taken at the northwest corner of the bulkhead near areas of observed underwater plant leakage, and a sediment sample taken off of the west shore which contained some of the white crystalline residue observed in this area and which was found to contain chromium carbonates.

Chromium was detected in only one of the three harbor water samples collected. This sample (S-3) was from the north shore area near where bulkhead leakages were reported. This sample contained approximately 14 mg/l total chromium, of which slightly more than half was in the hexavalent form.

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